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NEW TYPE OF MICROWAVE AMPLIFIER

/Figures referred to are appended./

V. M. Lopukhin

Introduction

The amplification and generation of centimeter and decimeter radio waves are important problems in contemporary microwave technology. This article describes a new type of microwave amplifier and generator, the term microwave being used here to include centimeter and decimeter waves. The design of the amplifier, which is based on the interaction of two parallel electron streams of different velocities, marks a significant advance in this field. [illegible]

In examining the new instrument, we draw the reader's attention to the physical side of the problem rather than to the technical details of tube design. We also recall the difficulties which are met when attempting to use normal circuits and tubes (such as triodes) for amplifying microwaves, so that the reader can judge the value of the new instrument in comparison with others used for the same purpose (1).

Normal oscillatory circuits, which consist of a lumped inductance L, capacitance C and resistance R, have a poor Q factor at microwave frequencies due to the small value of $\frac{L}{C}$ and to circuit emission of electromagnetic waves. An ordinary radio tube functioning in a grounded grid circuit also begins to operate badly at microwave frequencies. The finiteness of the transit time taken by the electrons between electrodes, which cause so-called transit effects, begins to have an adverse influence on the tube's operation. The resulting appearance of conductance in the cathode-grid spacing by-passes the oscillatory circuit and lowers the amplification factor.

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These facts make it necessary to revert to special closed circuits (endovibrators) which have a good Q factor, and to small tubes in which transit effects are negligible. Traveling-wave tubes, which have been described in a previous article (1), may also be used for this purpose. The operation of these tubes is based on the interaction of an electron stream and a slow electromagnetic wave whose velocity is approximately that of the average velocity of the electron stream. The electromagnetic wave can be slowed down by using a retarding field formed by a helix (2), an endovibrator [cavity resonator] system, or a series of conducting surfaces or "combs" (3). (See Figures 1, 2, 3.)

In the presence of an electron stream, the electromagnetic wave passing through the system is split up into three waves. One of these moves along with approximately the same velocity as that of the undisturbed electromagnetic wave in the absence of an electron stream, while the other two have a phase velocity slightly less than that of the electron stream. Of these last two, one attenuates exponentially with the coordinate and the other increases.

The increasing wave causes signal amplification. To use an analogy, an "electron wind" moving at a greater velocity than a wave produces an increase in its amplitude. The physical cause of amplification is that while an electron beam moves at a velocity greater than that of an exponentially increasing wave, electrons are bunched into the retarding regions of the wave (1).

The appearance of increases in amplitude during interaction between an electron stream and a retarded electromagnetic wave moving at almost the same velocity as the stream is a general characteristic of all types of retarding circuits. A traveling-wave tube used as a microwave amplifier has the following additional advantages (1, 4):

a. Long duration of interaction between the electron stream and the electromagnetic wave, which makes such interaction effective and gives good gain (in the tube described in (4), the gain is 23 decibels).

b. The broad pass band of an instrument using a helix (in the tube described in (4), the pass band is 800 Mc at a carrier frequency of 3600 Mc).

Electron-beam tubes with retarding circuits have the following disadvantages:

a. A very intense electromagnetic a-c field interacts with an electron stream and is concentrated close to the conducting surfaces of the retarding circuit. There is therefore an inevitable precipitation of electrons on these conductors, which causes a reduction in the efficiency of the instrument.

b. When using the circuit shown in Figure 2 as an oscillator, the frequency is determined by the resonance frequency of the endovibrators located on the periphery of the circuit. The Q factor of these endovibrators, and consequently of the circuit itself, are impaired when using shorter waves (such as millimeter waves), since the linear dimensions of the endovibrators are reduced in this case. Consequently, the circuits shown in Figures 2 and 3 are rarely used with good effect to generate millimeter waves.

The new type of electron-beam amplifier -- the double-beam or more generally the n-beam electron tube -- does not have the above disadvantages. The principle of the double-beam tube is extremely simple. Let us take two electron streams at the same voltage moving with slightly different velocities ξ_1 and ξ_2 (in the general case, n streams or even a continuous velocity dispersion would be considered) -- see Figure 4. It is found that in a given case of correlation of the velocity ξ_1 and ξ_2 the double-beam system acts as a negative resistance, so that if the slower electron stream is density- or velocity-modulated, this modulation will increase with the coordinate. A double-beam tube was constructed so as to make use of this negative resistance and a gain of 80 decibels was obtained at 3,000 Mc (λ=10 cm) with a pass band of 900 Mc.

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The physical operational principles of this tube and its comparison with a traveling-wave tube are given below. However, it is not too early to point to a similarity between a double-beam tube and an ordinary traveling-wave tube. The slower electron beam is velocity-modulated by the input signal and converted into a density-modulated beam. This modulated beam sets up a roughly periodic configuration through the tube and acts as a retarding field for the electromagnetic wave. The role of the periodic configuration is similar to that of the helix or "comb" in a traveling-wave tube. In this manner, the faster electron stream moves in a periodic field, and the physical problem therefore lies in the interaction of this beam with the retarded electromagnetic wave, i.e., it is the same as that of the traveling-wave tube.

/Section 2 contains details of the theory of the double-beam tube and includes mathematical formulas for the interaction of two interpenetrating electron streams. Section 3 describes some experimental double-beam tubes, discusses the work of A. V. Haeff and A. V. Hollenburg, and compares the theoretical and practical results of experiments. Section 4 contains mathematical data on the excitation of plasma by an electron stream, based on the theory that a double-beam tube can be approximated by plasma (i.e., a slow beam) which is penetrated by an electron beam./

Conclusions

The multibeam tube emerges as a new type of microwave amplifier and generator. Such a tube has an amplification factor of about 80 decibels and a very broad pass band ($\frac{\Delta\omega}{\omega} = 0.3$ where $\omega = 2\pi \cdot 3 \cdot 10^9$ so that $\Delta\omega = 900 \cdot 2\pi$ Mc). These characteristics of a multibeam tube are similar to those of a traveling-wave tube whose operation is based on the interaction of a retarded electromagnetic wave with an electron beam.

The disadvantages of the traveling-wave tube lie in the electron losses caused by their precipitation on the retarding field circuit (helix or endovibrator) and the resultant heating of the conductors. These losses are particularly great in the millimeter range. Multibeam tubes do not suffer from such losses, and it is therefore reasonable to suppose that they would be efficient microwave amplifiers and generators.

On the other hand, the weak point in multibeam tubes will be noise, because when the number of interacting electron streams is increased, the effect of density fluctuations in these streams also increases.

From the summary of existing theories on multibeam tubes given above, it is clear that a full and completely satisfactory theory for these tubes does not yet exist and that present theories are only approximations. At the same time, it is also clear that the multibeam tube is an extremely interesting instrument whose physical operational properties can be explained by A. A. Vlasov's theory of plasma in relation to the interaction of multielectron systems.

Phenomena observed in multibeam tubes bear a distinct resemblance to the Cherenkov phenomena and to the excitation of a retarding field (using a helix, "comb," plasma, etc.) by an electron system.

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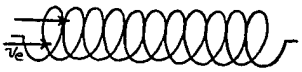
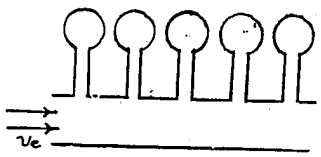


Figure 1. Helix and Electron Stream Used in a Normal Traveling-Wave Tube; V_e = electron velocity.

Figure 2. Endovibrator of the "Slot-Opening" Type Used for Retarding an Electromagnetic Wave; V_e = electron velocity.



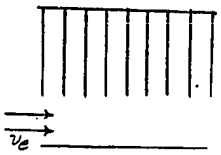
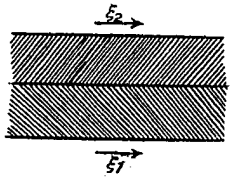


Figure 3. Series of Conducting Surfaces ("a comb") Used for Retarding an Electromagnetic Wave; V_e = electron velocity.

Figure 4. Negative Resistance Used in the New Microwave Amplifier Formed by Two Parallel Electron Streams Moving at Different Speeds ξ_1 and ξ_2.



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